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Article

Assessment of the Potential of Small Beads Reservoirs to Mitigate Climate Change Impacts in Urban Areas

Wanda Jarosz [1], Witold Mandrysz [2], Barbara Kalinowska-Wójcik [3], Jakub Grudniewski [3], Natalia Janczewska [4,5,6], Edyta Sierka [4], Damian Absalon [4,7], Łukasz Pieron [5], Marcin Lipowczan [4,8,*], Anna Piekarska-Stachowiak [4,8], Magdalena Matysik [4,7], Dawid Depta [8], Weronika Walkowiak [4,6], Magdalena Biela [5] and Andrzej Woźnica [4,8]

[1] The Institute for Ecology of Industrial Areas (IETU) Instytut Ekologii Terenów Uprzemysłowionych PIB, ul. Kossutha 6, 40-844 Katowice, Poland; wanda_77@o2.pl

[2] Institute of Sociology, Faculty of Social Sciences, University of Silesia Instytut Socjologii, Uniwersytet Śląski w Katowicach, Bankowa 11, 40-007 Katowice, Poland; witold.mandrysz@us.edu.pl

[3] Institute of History, Faculty of Humanities, University of Silesia Instytut Historii, Uniwersytet Śląski w Katowicach, Bankowa 11, 40-007 Katowice, Poland; barbara.kalinowska-wojcik@us.edu.pl (B.K.-W.); jakub.grudniewski@us.edu.pl (J.G.)

[4] Silesian Water Centre, Śląskie Centrum Wody, University of Silesia Uniwersytet Śląski w Katowicach, Bankowa 5, 40-007 Katowice, Poland; natalia.janczewska@us.edu.pl (N.J.); edyta.sierka@us.edu.pl (E.S.); damian.absalon@us.edu.pl (D.A.); anna.piekarska@us.edu.pl (A.P.-S.); magdalena.matysik@us.edu.pl (M.M.); weronika.walkowiak02@gmail.com (W.W.); andrzej.woznica@us.edu.pl (A.W.)

[5] Doctoral School, University of Silesia in Katowice, Bankowa 14, 40-007 Katowice, Poland; lpieron1@us.edu.pl (Ł.P.); magdalena.biela@us.edu.pl (M.B.)

[6] State Water Holding Polish Waters, National Water Management Authority, Żelazna 59A, 00-848 Warszawa, Poland

[7] Institute of Earth Science, Faculty of Natural Science, University of Silesia, Będzińska 60, 41-200 Sosnowiec, Poland

[8] Institute of Biology, Biotechnology and Environmental Protection, Instytut Biologii Biotechnologii i Ochrony Środowiska, Faculty of Natural Science, University of SilesiaUniwersytet Śląski w Katowicach, Jagiellońska 28, 40-032 Katowice, Poland; dawidtriops@o2.pl

* Correspondence: marcin.lipowczan@us.edu.pl

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Abstract: This study examines historical water management practices as a means of addressing climate change, focusing on the Tyski Stream catchment in Upper Silesia, Poland, a region marked by extensive urbanization and industrial evolution. It investigates the effectiveness of historical hydrotechnical systems, such as bead-like ponds from the 15th to 18th centuries, in enhancing water retention, reducing flood risks, and supporting ecosystem services. In a critical period, over 54 years (1827–1881), the number of reservoirs decreased from 142 to 31 (the area of ponds decreased from 161 to 32 ha). Throughout the entire period, between 1748 and 2017, the surface area of the analyzed reservoirs decreased from 163 ha to 16.8 ha. This was related to progressive industrialization, urban sprawl, and changes in legal frameworks, such as land ownership laws, leading to ecosystem degradation, loss of biodiversity, and altered hydrological processes. The research emphasizes the potential of reviving historical water management systems on natural processes to mitigate the impacts of climate change. By analyzing historical cartographic resources, this study assesses the feasibility of reconstructing lake systems in areas with similar topographic and hydrological features. It also stresses the necessity of community engagement and securing widespread social and political support to ensure public acceptance and the success of renaturation initiatives. The findings indicate that restoring these systems can offer diverse benefits, including improved water management, enhanced biodiversity, and greater urban resilience, while addressing the socio-political complexities of implementing large-scale environmental restoration projects. The aim of this study is to utilize archival materials for engineering solutions to prevent flooding and enhance water retention.

Keywords: water resources; historical maps; reservoir reconstruction; bead-like ponds; climate change; adaptation

1. Introduction

Current climate changes necessitate the optimized management of environmental resources. Freshwater ecosystems, particularly riverbeds, are among the most transformed elements of the environment [1,2]. In urban areas, the negative impacts of climate change are expected to be especially pronounced. According to future scenarios of climate change and urbanization, the comfort and well-being of urban populations during the summer months are increasingly at risk [3]. In this context, it is worth examining historical water management solutions, which were dominant until the late 18th century, based on nature and the use of environmental resources.

In non-urbanized areas, riverbeds include meanders and small water bodies created by natural obstacles such as beaver dams or accumulations of plant material [4,5]. In Upper Silesia, there are no natural water reservoirs, except for abandoned river meanders/oxbows. In historical times, watercourses were modified with various hydrotechnical devices, such as cross-dams called by Strumieński "causeways from hill to hill" [6–8], forming "bead-like ponds" systems. These cascading ponds, fed by streams and drainage ditches, efficiently retained water and were used for various purposes. This approach to water management remained prevalent until the late 18th century. The difference in level between the first and last pond ranged from a few meters to several tens of meters [7]. Usually, the system of such reservoirs starts with a spring reservoir built on the sources of rivers and streams.

Historical analyses indicate that Poland, like the rest of Europe, experienced significant climatic fluctuations [9–12], including periods of increased precipitation in the 12th, 16th, and 18th centuries [13]. Intense flooding in the late 16th century [14] necessitated the construction of large reservoirs along rivers to mitigate flood risks [15]. Clearing mountain forests for pastoralism in Karpaty and urban development reduced the region's water retention capacity [16,17]. The industrialization of Upper Silesia further transformed aquatic ecosystems, with water pollution from mining and metallurgy intensifying from the late 19th and early 20th centuries onwards. After major floods, the location and size of ponds changed significantly, and some ponds were transformed into arable fields [10].

The reservoirs built in the area of Wolne Pszczyńskie Państwo Stanowe (the Free State of Pszczyna) from the 15th to the mid-19th century served a range of critical economic functions, including fish farming, water retention for powering mill wheels, and flood protection [17,18]. The high level of technical culture in Upper Silesia from the 16th century onward fostered the development of hydrotechnical ideas and the construction of advanced hydrotechnical structures for harnessing energy to power devices in mills, forges, fulling mills, and sawmills [2,7,19]. This significantly contributed to the shaping of aquatic ecosystems in the region [16]. In addition to these functions, which were consciously utilized by the people of that time, other ecosystem functions also emerged, such as carbon sequestration, microclimate regulation, and biodiversity enhancement [20–23]. On the other hand, the lowering of groundwater levels in riparian areas led to changes in vegetation cover. This, in turn, necessitated the deepening of wells and water intakes. From the second half of the 18th century, efforts to regulate rivers began. From the late 19th to early 20th century, water pollution in Silesian rivers intensified [16] due to the development of industry, particularly metallurgy and mining, as well as rapid urbanization [24–27].

Ecosystem functions provided by aquatic ecosystems underwent significant devaluation by the end of the 18th century, driven by a decline in the demand for fish for consumption and the replacement of water wheels with steam-powered and later electric machines [25]. Intensive industrialization in the area of Wolne Pszczyńskie Państwo Stanowe, resulting from the use of steam engines, the exploitation of hard coal, and iron and metal ores [28,29], initiated changes that led to a gradual departure from blue energy and transformed the management of surface water systems. The high costs of maintaining water systems, such as bead-like ponds, caused a sharp decline in their share of catchment areas [30]. Moving away from nature-based solutions resulted in the loss of essential ecosystem functions, including carbon sequestration, biodiversity maintenance, water purification, and fish production for consumption. Due to the high cost of maintaining wetlands, ponds began to be drained, and their fertile beds were converted into arable land through the establishment of drainage systems [16,31–33]. The elimination of meanders, oxbow lakes, and interventions in riverbeds, including riverbed construction, permanently altered aquatic and water-dependent ecosystems, reducing their landscape value [2].

The reduction in the number and area of ponds in Upper Silesia is attributed to the lowering of the water levels in the first aquifer, the abandonment of water retention practices, and the decline of pond-based fish farming [30]. In Upper Silesia, the lowering of groundwater levels was a consequence of coal mining, necessitating the drainage of underground workings, but it could also have been caused by drought [14,15]. An important factor influencing changes in legal and ownership relations was the process of the legal emancipation of peasants, which transformed the ownership structure of agricultural lands and areas previously occupied by water reservoirs and forests. Owners of small agricultural holdings generally refrained from more significant economic initiatives, such as maintaining fish ponds, instead focusing on meeting basic nutritional needs that required minimal financial and organizational resources [34].

In modern times, the ongoing urbanization of the region has led to areas once occupied by former ponds being repurposed for residential construction. Such use of these lands poses significant risks due to surface sealing and the lack of proper water drainage during heavy, sudden, or prolonged rainfall. Former reservoir basins can still accumulate water, leading to localized flooding.

The described changes in environmental management are particularly evident in historically heavily industrialized and urbanized areas, where industrial activities initially relied on renewable water energy (water wheels), which in the 19th century were replaced by steam engines, and where the exploitation of hard coal deposits expanded [35–38]. One such area is the northern part of the former Wolne Pszczyńskie Państwo Stanowe—now the southern section of Górnośląsko-Zagłębiowska Metropolia (GZM) (the Upper Silesian-Zagłębie Metropolis). The shift away from coal-based energy and the return to nature-based solutions presents new challenges related to the restoration of the heavily altered areas of GZM, offering an opportunity to restore the region's historically advanced water management systems.

The study focused on analyzing the catchment area of Potok Tyski (Tyski Stream), located in the central part of Rzeka Gostynia (the Gostynia River) basin, which featured numerous bead-like ponds in the 17th and 18th centuries. Today, this area is heavily urbanized and includes the districts of Tychy: Wilkowyje, Stare Tychy, and Urbanowice.

Using historical cartographic materials to design methods to restore lake systems in the Upper Silesia region and mitigate the effects of climate change appears justified. This is because the same area is being utilized, with similar topography and a catchment area comparable in supply and size to its historical counterpart [39–41].

It is important to remember that such changes will have specific consequences for individuals, groups, and communities where restoration efforts are to be undertaken. For these solutions to gain acceptance, it is essential to raise public awareness of the benefits of such changes and to engage and motivate local communities to participate in shaping the direction of these transformations. In this context, seeking a broadly understood consensus among local socio-political actors and various interest groups is justified. Developing solutions accepted by a broad representation of social, economic, and institutional-political entities increases the likelihood of effectively implementing projects that gain public understanding, thereby reducing protests from groups excluded from the decision-making process.

The aim of this study is to inventory historical bead-like ponds, analyze the reasons for the decline of lake systems in the Potok Tyski catchment in the 19th century, and assess the feasibility of restoring historical hydrotechnical solutions to the resilience of climate change in the urbanized area of the GZM. Additionally, this study seeks to evaluate the social acceptance of such solutions.

2. Materials and Methods

2.1. Study Area

The analysis focused on the catchment area of Potok Tyski (PLRW20006211869), a left-bank tributary of Rzeka Gostynia. Rzeka Gostynia is a left tributary of the Vistula River, with a length of 346.34 km^2 and a catchment area of 346.34 km^2. Potok Tyski is located in the central part of the Rzeka Gostynia basin, with a catchment area of 23.89 km^2. Administratively, the Potok Tyski catchment lies within the Silesian voivodeship, spanning Tychy Miasto (Tychy City County) (81.14% of the catchment), Mikołów (Mikołów County) (16.16%), Bieruń-Lędziny (Bieruń-Lędziny County) (2.17%), and Katowice (Katowice City County) (0.52%). It encompasses urbanized areas of Tychy (the districts of Wilkowyje, Stare Tychy, and Urbanowice) and agricultural and forested areas in the northwestern part of the catchment. Potok Tyski, 13.26 km in length, drains the Mikołów Ridge toward the valleys of Rzeka Gostynia and the Vistula River, with an elevation difference of 49 m between its source and mouth. It flows into Rzeka Gostynia at the 12.7 km mark. Its largest tributary is the right-bank Potok Nowotyski (the Nowotyski Stream), which is 6.26 km long with a gradient of 68 m. It joins Potok Tyski at the 3.8 km mark near Urbanowice. The streambed of Potok Tyski is approximately 1 m wide, with a channel width ranging from 2 to 4 m (Figure 1).

Over the centuries, this area has undergone significant transformations [42]. Today, it is heavily urbanized, yet despite the considerable changes in the catchment, remnants of hydrotechnical solutions from the 18th and 19th centuries can still be observed [43]. Geographically, this area lies at the border of Równina Pszczyńska and Wyżyna Katowicka (the Pszczyna Plain and Katowice Upland) mesoregions [44].

2.2. Archival Materials: Cartographic

This study used cartographic materials illustrating changes in the management of natural resources in the area under investigation. Historical maps covering the Potok Tyski catchment were selected for the analysis. The archival research was primarily conducted in Polish and German archives, libraries, and digital cartographic repositories. Topographic sectional maps showing the analyzed area at scales ranging from approximately 1:17,000 to 1:25,000 were chosen, allowing for a more detailed analysis of the hydrological network.

The oldest surviving map depicting the analyzed catchment area is IXNOOPΘOGPAΦIA PLESNIACA—Andreas Hindenberg's map from 1636. Due to the measurement technique, this map allows only an approximate location of large river ponds [45]. Its low level of detail and poor cytometric accuracy prevent the determination of their surface area. The map also does not show the location of most of the bead-like ponds. Despite not being to scale, it was used in the study due to its unique character and significant research value.

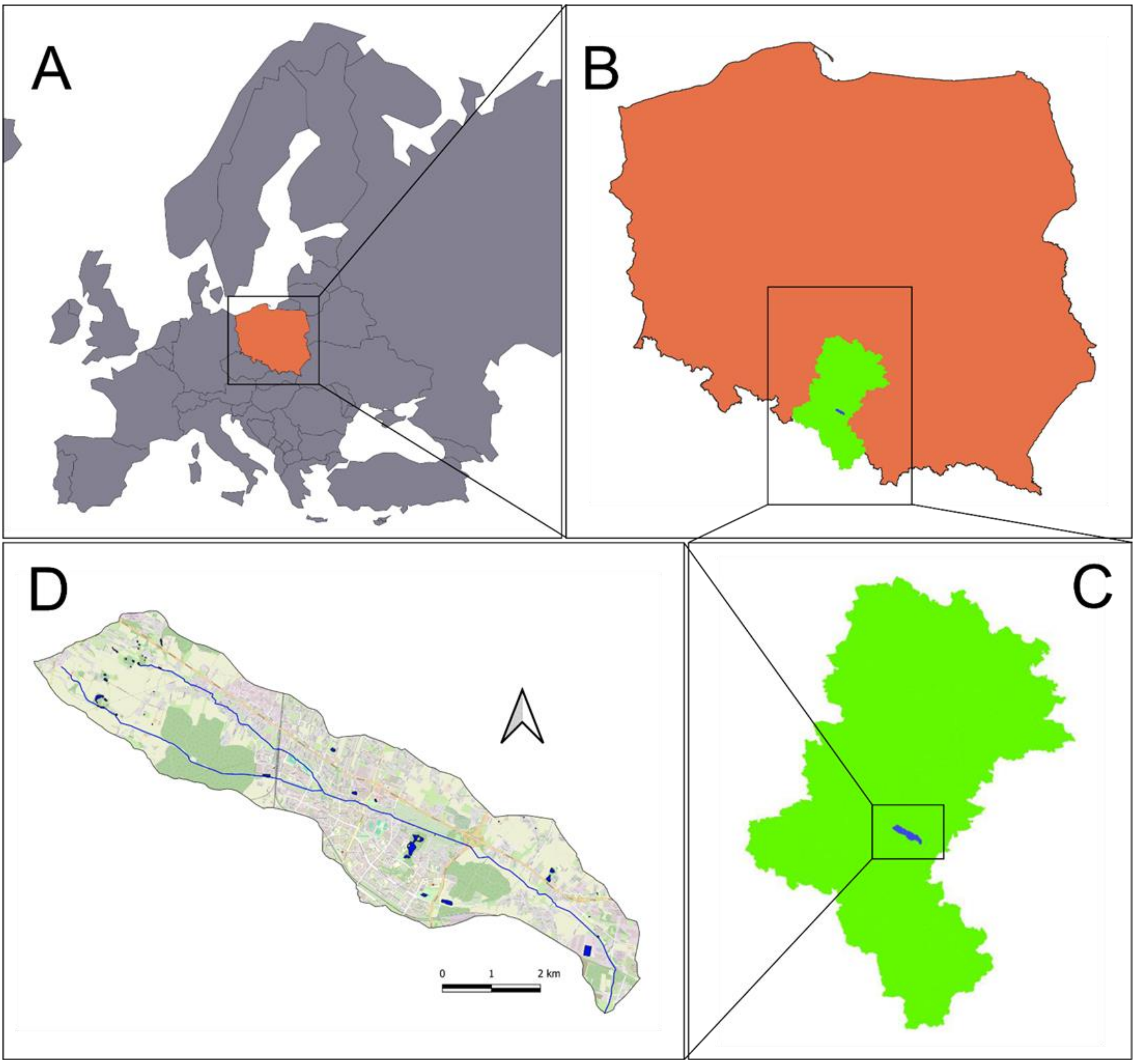

Figure 1. Location of the Potok Tyski catchment area: (**A**) in Europe; (**B**) in Poland; (**C**) in Silesian voivodeship and (**D**) map of Potok Tyski catchment area (Open Street Map).

For the 18th and 19th centuries, cartographic collections stored in the Staatsbibliothek Berlin were used. This primarily includes a map from the Krieges-Carte von Schlesien atlas by Christian Friedrich von Wrede (ref. 2″Kart. N 15060-2), created for the area of interest in 1748–1749, at a scale of 1:34,000, with specific Sections 31, 32, 34, and 33. The map was made for military purposes but is a vibrant source of information about the hydrological and communication networks, the level of urbanization, and the proto-industrialization of these areas. The map also marks the terrain's morphology, depicted using the hachure shading method.

For the first half of the 19th century, the first topographic map of Upper Silesia created using the triangulation method was selected—the Preußischen Urmeßtischblätter (hereafter referred to as Urmeßtischblatt), prepared in 1827 at a scale of 1:25,000, and also preserved in the Staatsbibliothek Berlin (catalog number/sygn. Kart. N 729). The area of interest is in the following sections: 3391 Nicolai and 3392 Lendzin.

For the second half of the 19th century, a topographic map created as part of a significant Prussian cartographic imaging initiative begun in 1877 using the polyhedral projection method was selected—the so-called Meßtischblätter (TK 25). The analyzed area is found on the following map sections: 3391 Nicolai and 3392 Lendzin, prepared in 1881 at a scale of 1:25,000. This map was produced in multiple copies and is available in numerous archives, libraries, and cartographic repositories.

The Map of the Hydrographic Division of Poland at a scale of 1:10,000 (MPHP 10K, 2017) was used to analyze the contemporary hydrographic network and lake coverage. For the analysis of historical land use, the Urmeßtischblatt map of the studied areas was vectorized using a HUION Kamvas Pro 20 graphics tablet (China).

To analyze land use in the catchment area, current databases of topographic objects (BDOT) were utilized, while for spatial management analysis of the catchment area, the Urban Atlas 2018 databases were employed.

Spatial analyses were performed using QGIS 3.30 software, and 3D spatial modeling was conducted with Surfer® version 23 (Golden Software).

Historical maps were registered relative to the contemporary Open Street Map (OSM) and the MPHP 10K hydrographic system using the Georeferencer plugin (QGIS 3.30) through Helmert transformation with Nearest Neighbor resampling methods. Subsequently, they were rectified to the geodetic coordinate system EPSG 2180: ETRF 2000-Pl/CS92.

2.3. Methodology of Social Research

Regarding the social aspects of the conducted research, the focus was on analyzing the social perception of rivers, streams, and water bodies located within the areas of the studied communities, as well as the public reception of their restoration efforts. The specificity of such research and the subject matter it addresses suggests the adoption of qualitative analysis assumptions, followed by selecting appropriate methods for collecting empirical material. A characteristic feature of such methods is the relatively small number of respondents, which allows for a more thorough and comprehensive analysis of their views, opinions, and reactions [46,47]. Focusing on a small number of cases enables a deeper understanding of their perspectives and insight into what occurs during interpersonal interactions, through which the socially constructed world imbued with meaning is continuously created and re-created [48]. In this context, the primary research method was the qualitative interview, an interaction between the researcher/interviewer and the respondent—an In-depth Interview (IDI). The interviewer operates with only a general research plan rather than a specific set of questions to be asked using predefined words and in a fixed order. The interviewer must be thoroughly familiar with the research topic and the questions they intend to ask [47,49]. The guided semi-structured (focused) interviews were employed for the expert interviews and interviews with so-called privileged observers. This approach allowed researchers to use what are known as interview dispositions—essentially a general list of issues or topics for discussion [50]. Interviewers had significant freedom in formulating questions tailored to individual respondents' specific expert knowledge and experiences. This open-ended nature enabled respondents to express their opinions on the given topics fully. The panel of experts interviewed was composed of people who, because of their profession, professional background, social involvement, or other experiences, have specific knowledge and competencies, important and interesting in the context of the research. This knowledge is unique in that it does not form part of the literature on the subject or general knowledge, but is strictly the result of the reflections of specific individuals in relation to their professional and socio-organizational background. The experts included the following: representatives of the authorities of companies and public institutions dealing with water management in the broadest sense—the Regional Water and Sewage Company in the Silesian Agglomeration and the Regional Water Management Authority—Wody Polskie; researchers with a rich scientific and publication output in the field of the subject matter undertaken in the project; environmental activists and educators; social activists active in areas where there are conflicts concerning spatial development in the vicinity of rivers; specialists in natural inventories and ecological impacts; and people who, due to their interests, have a rich knowledge of archival maps and cartographic documents of the studied area.

Another research method used to collect qualitative empirical data was Focus Group Interviews (FGI) with residents of selected communities [51–54]. In practice, the research involved moderating a discussion among a group of respondents (members of local communities) on a topic set by the researcher. The main task was to uncover the participants' views, opinions, feelings, and attitudes regarding a specific issue—in this case, the perception of rivers, streams, and water bodies present in their environment and also climate change. The discussion followed a pre-developed script that addressed various aspects, including historical context, changes in land use, natural functions, problems and risks associated with the proximity of these watercourses to residential areas, potential directions for change, and other related topics.

The discussion groups comprised 7–12 participants, lasting approximately 1.5–2 h. Visual materials developed during earlier stages of interdisciplinary research (maps, drawings, photographs, sketches, models, etc.) were very useful in moderating conversations about the specific area under study.

3. Results and Discussion

Historical water management practices offer valuable guidance. Materials from coal mining regions provide numerous opportunities to improve environmental conditions. These procedures can be applied during the transition of energy economies from coal-based systems. One main focus is increasing the water retention capacity of urban areas and restoring watercourses as tools for environmental regeneration and mitigating human impacts [55]. National and international policy frameworks play a key role in supporting the large-scale implementation of blue-green infrastructure [56–59]. The importance of restoration is emphasized by numerous regulations, including the EU Water Framework Directive [60], which aims to prevent further deterioration of aquatic ecosystems and achieve "good water status". Similarly, Poland's Water Law [61] mandates the preservation of the condition of surface waters and the restoration of ecosystems degraded by inappropriate or excessive water management.

3.1. Spatial Development

The analysis of land use changes in the Potok Tyski catchment area was conducted based on the vectorized Urmeßtischblatt map from the early 19th century (Figure 2E,F) (Urmeßtischblatt, 1827) and the Urban Atlas (Figure 2A–D) (Urban Atlas, 2018). The results indicate significant changes in land use forms. The current dominance of urbanized areas has resulted in the near-total disappearance of wetlands and a tenfold decrease in the presence of lakes. Analyses of the extent of modern built-up areas and road surfaces indicate land impermeability, leading to accelerated water runoff in these regions. The reduction in lake coverage points to a low presence of blue infrastructure in urbanized areas. This is particularly concerning given the crucial role such areas play in water retention and climate change adaptation. Notably, the forestation rate has remained steady over the past 200 years, with forested areas comprising approximately 12% of the catchment area in 1827 and 2018.

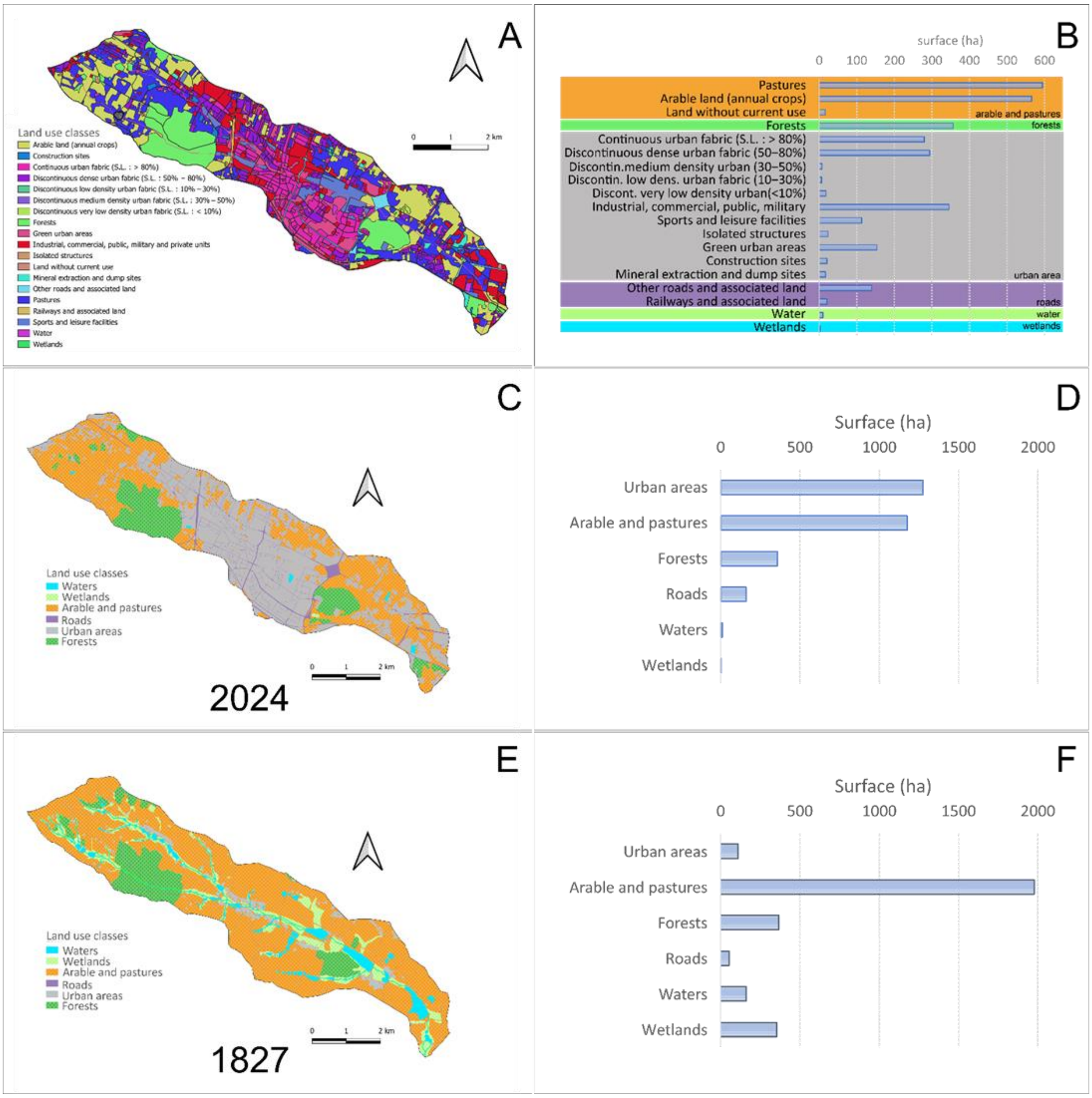

Figure 2. Analysis of spatial development of Potok Tyski catchment area: (**A**–**D**) based on Urban Atlas 2018 and (**E**,**F**) based on Urmeßtischblatt (1827). For comparison, in Figures (**C**,**D**), land use types were aggregated to the types presented on the Urmeßtischblatt map.

3.2. Inventory and Identification of Former Water Reservoirs

An inventory of historical and contemporary water bodies in the Potok Tyski catchment area was conducted based on the historical Urmeßtischblatt map (1827) and the modern MPHP 10K map (2017).

As early as Hindenberg's map from 1636, the Potok Tyski catchment area was rich in numerous water bodies [43]. Analyses of Wrede's maps and Urmeßtischblatt (Wrede 1748–1749; Urmeßtischblatt 1827) indicate a significant presence of land covered by water in this area. The catchment was dominated by bead-like ponds—small, flow-through reservoirs arranged in series, constructed in river valleys based on the terrain's shape and damming of the valley with embankments. In the Potok Tyski catchment, 7 such pond systems were identified, each consisting of 5 to 14 reservoirs. A total of 142 ponds were located, with a combined area exceeding 161.15 hectares (Table 1), resulting in a lake coverage rate of 6.8%. The average pond size was approximately 1 hectare, with the most extensive ponds reaching up to 4.5 hectares. These ponds were supported by 91 embankments with an estimated length of 11.28 km. In the lower reaches of the streams, there were 3 large, flow-through river reservoirs with a combined estimated area of 65 hectares (Urmeßtischblatt 1827).

Table 1. Classification of ponds in Potok Tyski catchment area over the centuries based on old maps and MPHP 2017. Number and area of ponds in Potok Tyski catchment area over the centuries based on old maps and MPHP 2017. QGIS 3.30. was used to vectorize pond images and estimate their area.

Surface Class [ha]	2017		1881		1827		1748	
	Water Reservoirs							
	Number	Total Area [ha]	Number	Total Area [ha]	Number	Total Area [ha]	Number	Total Area [ha]
0–1	48	7.25	22	7.23	111	29.76	42	27.21
1–5	5	9.55	8	14.84	28	66.07	39	67.08
5–10	-	-	1	9.97	-	-	1	7.58
10–20	-	-	-	-	1	13.68	1	15.71
More than 20	-	-	-	-	2	51.64	2	45.64
Total	53	16.8	31	32.04	142	161.15	85	163.21

Cartographic analyses indicate that the estimated area of bead-like ponds recorded on maps may be understated due to the significant seasonal variability in their water levels. The large proportion of small water surfaces suggests that they may have been recorded during periods of partial drainage.

In the second half of the 19th century, a significant decline in the number and area of water bodies in this region was observed. For bead-like ponds, this could have resulted from the dynamic fluctuations in water levels caused by using retained water to power mill wheels. For fish ponds, river reservoirs, bead-like ponds, and embankment reservoirs, the decline may also have been caused by the reclamation practices of periodically draining the reservoirs and applying agrotechnical treatments. Such practices are described by Strumieński [7] and Nyrek [32,33]. These methods involved removing nutrients from bottom sediments by cultivating usable plants within the reservoir basin.

Consequently, dry reservoirs resulting from these practices can be observed on maps. These changes initiated the drying of bead-like ponds, with their number and area decreasing threefold by 1881, leaving 31 ponds with a total area of 32 hectares. Lake coverage in this area has decreased tenfold, leaving only about 16 hectares of water bodies (Urmeßtischblatt 1827, MPHP 2017). Detailed information is presented in Figure 3.

3.3. Possibility of Reconstruction of Former Water Reservoirs and Spatial Collisions and Social Conflicts

The analysis of historical materials and the Digital Terrain Model (DTM) indicates the potential for restoring some of the previously existing bead-like ponds. The criterion for assessing the feasibility of such restoration is the presence of spatial conflicts and social disputes (Figures 4–7). Figure 4 illustrates one of the systems of former bead-like reservoirs. Their restoration is facilitated by the terrain's topography and the remnants of embankments still in the area. However, spatial conflict analysis reveals that the basins of these reservoirs have been developed in modern times, making their restoration impossible.

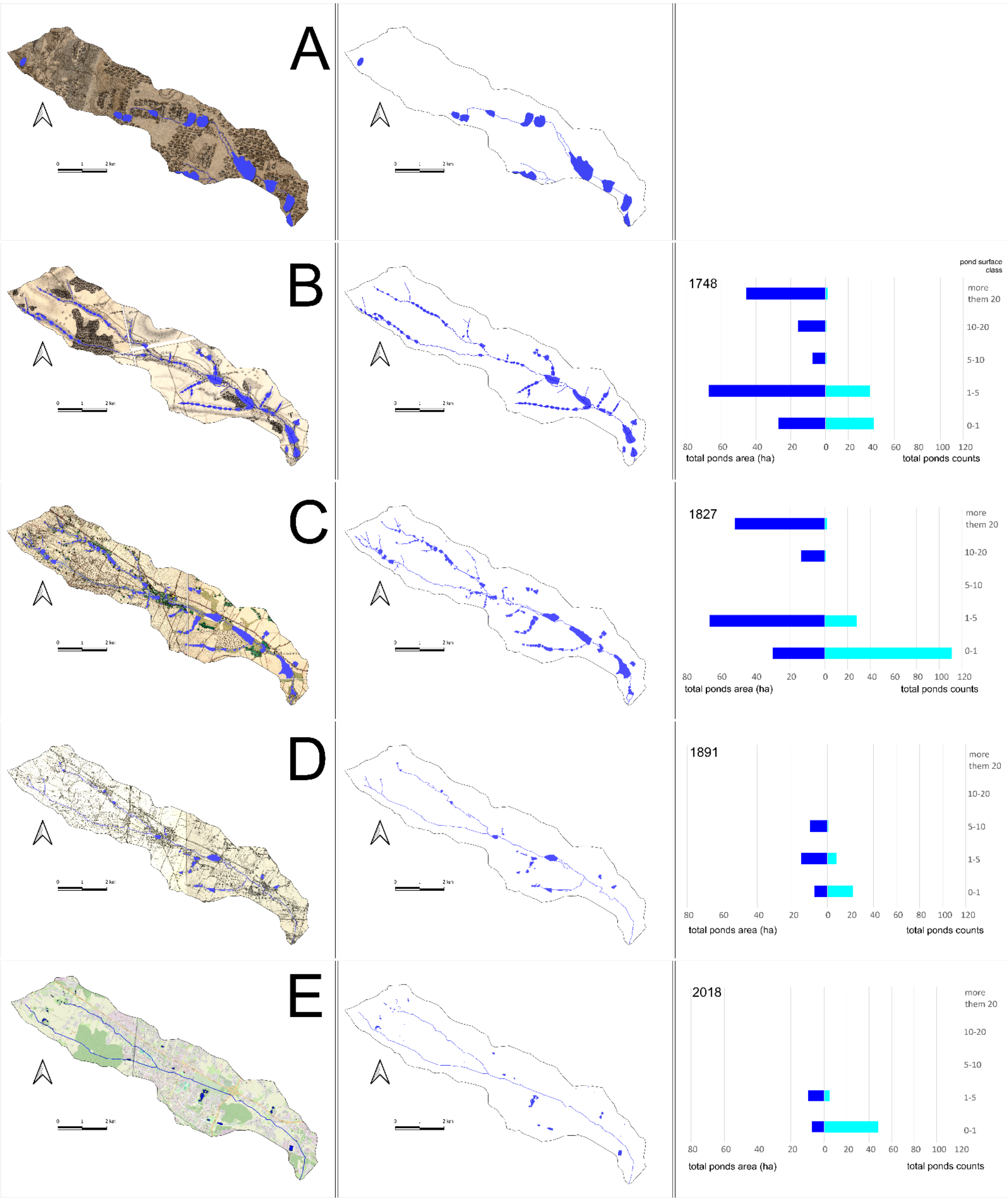

Figure 3. Inventory and classification of water reservoirs and river networks of Potok Tyski catchment area over the centuries according to (**A**) Hindenberg 1636; (**B**) Wrede 1748–1749; (**C**) Urmeßtischblatt 1827; (**D**) Meßtischblatt 1881; (**E**) orthophotomap + MPHP 10K (2017).

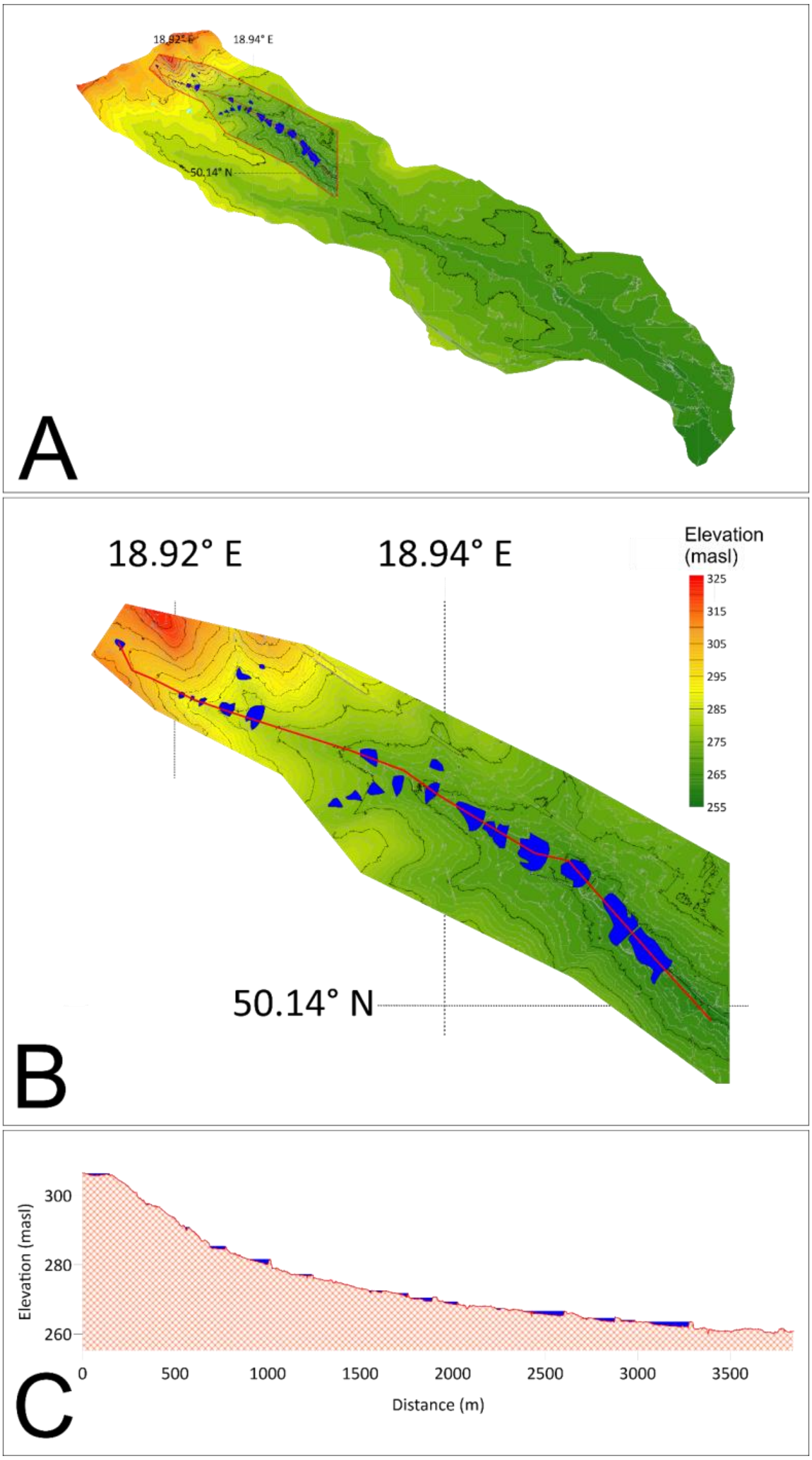

Figure 4. Analysis of the location of former bead-like ponds pearl reservoirs using DTM 2012 in a highly urbanized area. (**A**) Location of the area of the analyzed former reservoirs against the background of a hypsometric map (red frame); (**B**) former reservoirs against the background of a hypsometric map; (**C**) catchment profile in the line of reservoirs of the upper section of the Tyski Potok catchment. Location of reservoirs based on Urmeßtischblatt (1827).

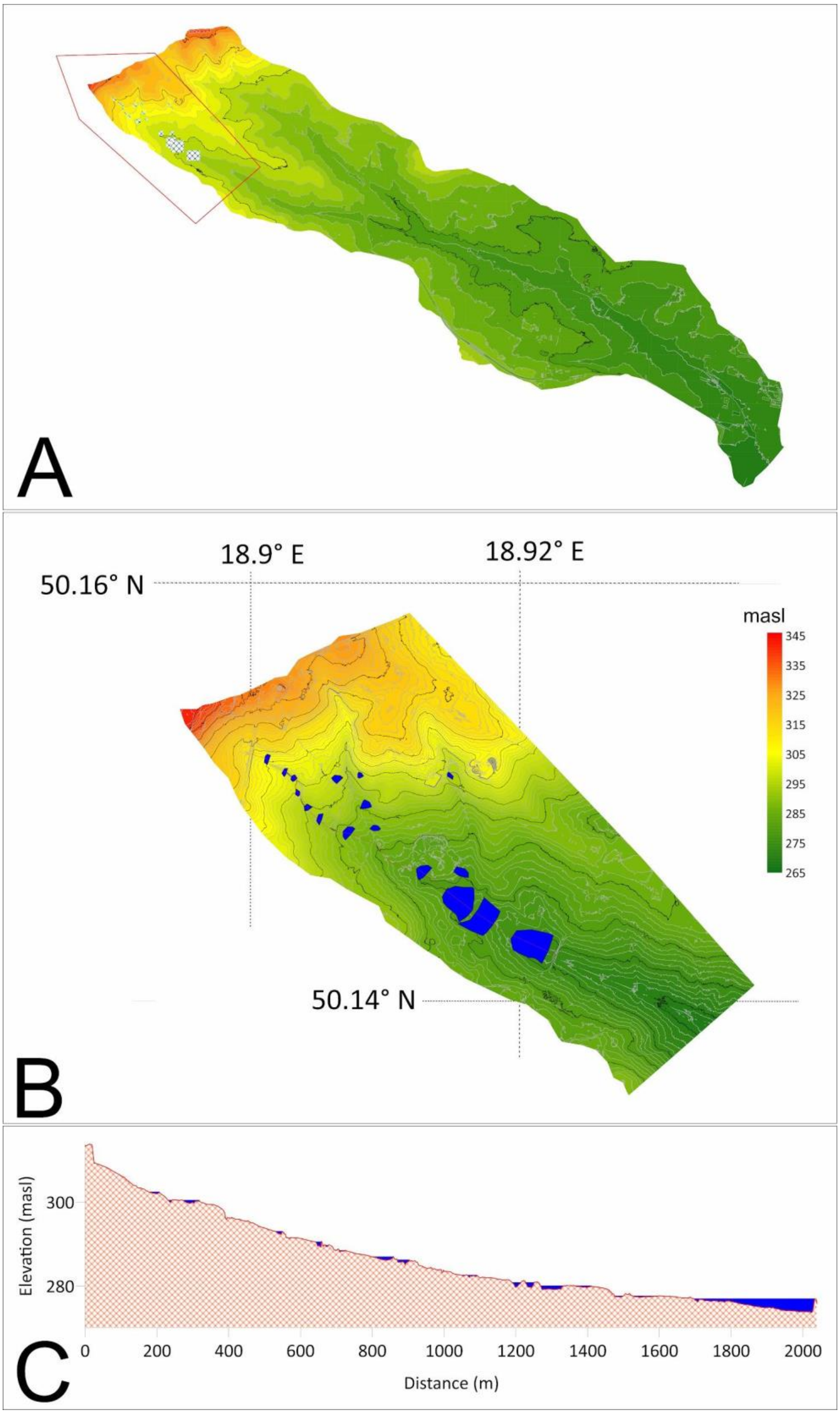

Figure 5. Analysis of the location of former pearl reservoirsbead-like ponds using DTM 2012 in a poorly urbanized area. (**A**) Location of the area of the analyzed former water reservoirs against the background of a hypsometric map (red frame); (**B**) former water reservoirs against the background of a hypsometric map; (**C**) catchment profile in the line of reservoirs of the upper section of Tyski Potok catchment. Location of reservoirs based on Urmeßtischblatt (1827).

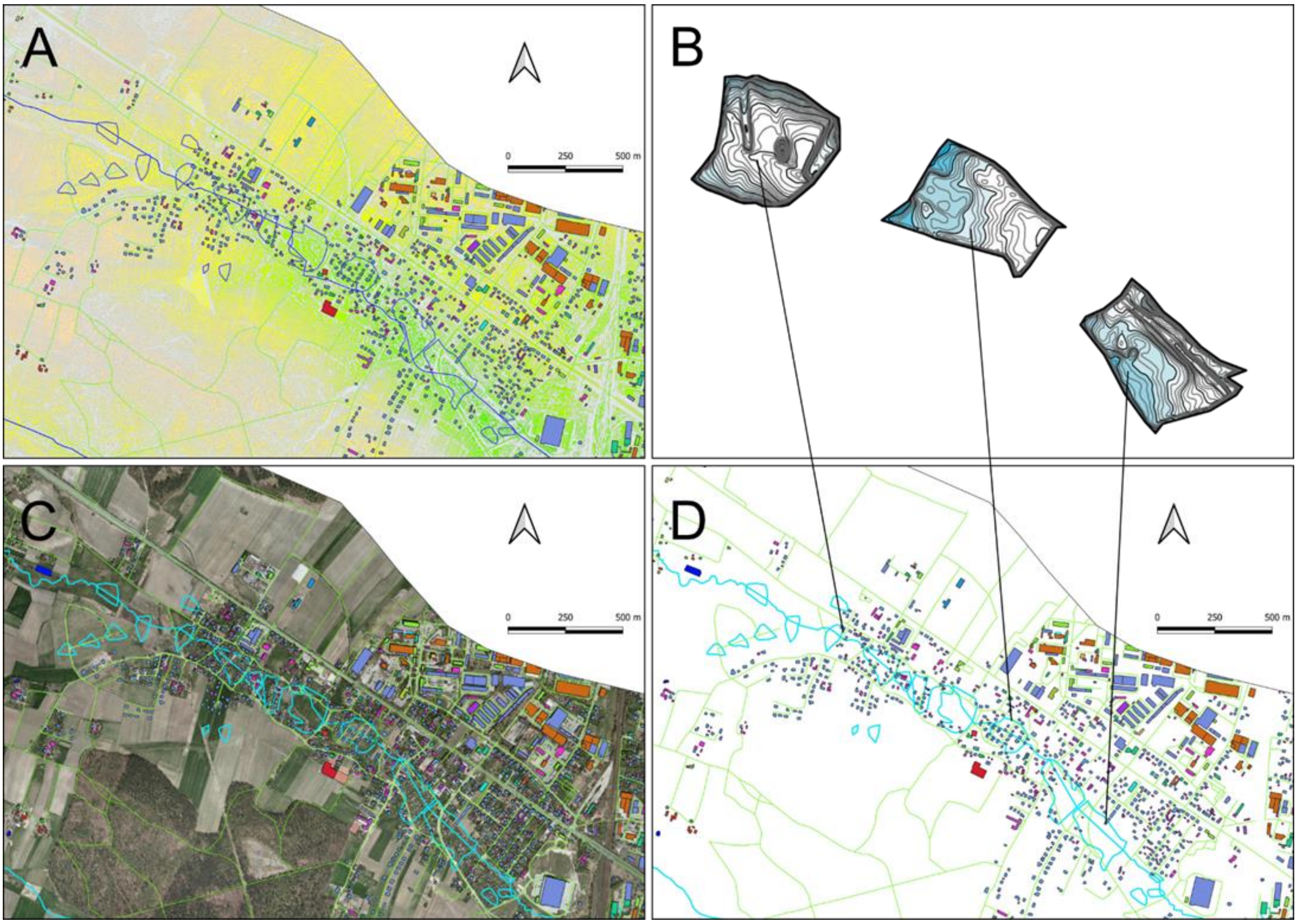

Figure 6. Spatial collisions of digitally reconstructed bead-like ponds pearl reservoirs in Potok Tyski catchment basin based on DTM and the Topographic Object Database (BDOT 2022) in a heavily urbanized area. (**A**) Former water reservoirs of Potok Tyski catchment basin and structure of contemporary urban development (BDOT); (**B**) attempt to reconstruct the bowl of selected pearl reservoirs basedbead-like ponds on DTM. (**C**) Former water reservoirs of Potok Tyski catchment basin against the background of an orthopotomap (2023); (**D**) location of roads and buildings according to the Topographic Object Database (BDOT 2022).

Spatial conflicts and social disputes arise due to the organization of spatial structures and stem from the differing goals of various entities operating within the same space [62]. While spatial conflicts primarily affect multifunctional areas where the natural overlap of different land use functions occurs, social disputes often result from factors such as legal gaps in spatial planning and landscape protection, as well as a lack of public awareness regarding the need to preserve the natural and cultural values of landscapes [63].

Overlaying the vector-based databases of historical and contemporary topographic features shows that spatial conflicts occur in various areas, not only multifunctional ones. Collision zones mainly concern transport and technical infrastructure routes, urban pressure, and the negative impact on the natural environment. However, only some negative impacts indicate conflicts between wetland areas and water bodies with modern urban development. The analysis of hypsometric images generated from the Digital Terrain Model (DTM) shows the development of the valley floor zone with the basins of former water reservoirs—Figure 7 points to an increased flood risk in these areas. The possibility of flooding these areas is confirmed by collected documentation, which shows that former reservoir areas in Wilkowyje (a district of Tychy) were flooded in the 1960s and 1970s.

This area is now heavily urbanized. The risk of such flooding results from the location of residential buildings directly in the stream's valley, which are divided by numerous former dykes/embankments, which now carry modern roads. This situation prevents using former water reservoir areas and floodplains to construct (or reconstruct) blue-green architecture.

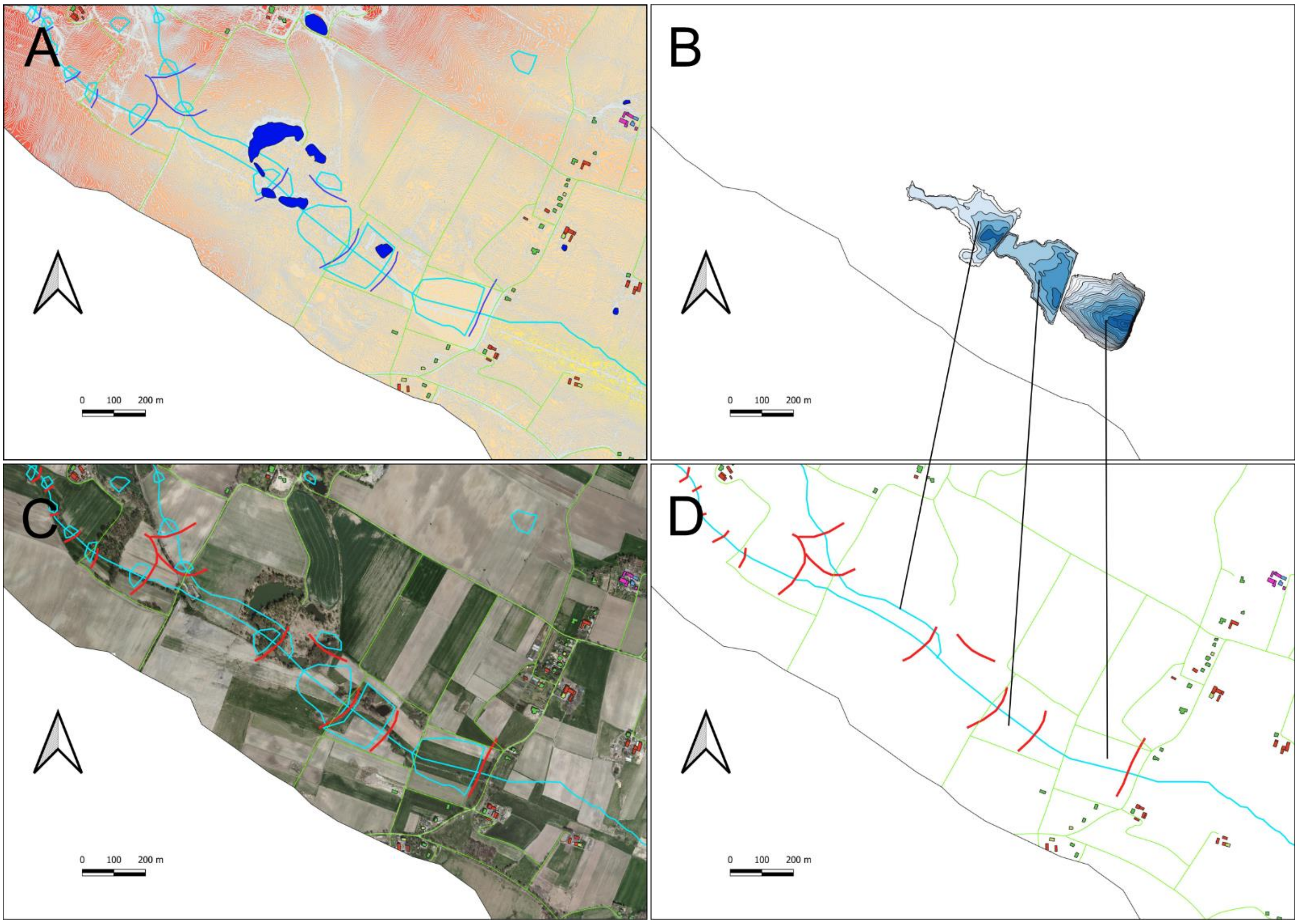

Figure 7. Spatial collisions of digitally reconstructed bead-like ponds pearl reservoirs in Potok Tyski catchment basin based on DTM and the Topographic Object Database (BDOT 2022) in a poorly urbanized area. (**A**) Former water reservoirs of Potok Tyski catchment basin and structure of contemporary urban development (BDOT); (**B**) attempt to reconstruct the bowl of selected bead-like ponds based on DTM. (**C**) Former water reservoirs of Potok Tyski catchment basin against the background of an orthophotomap (2023); (**D**) location of roads and buildings according to the Topographic Object Database (BDOT 2022).

In the Potok Tyski catchment area, 141 ponds with an estimated area of 161 ha were identified (Figure 8A). Conflicts with contemporary spatial development elements were found in the case of 70 ponds with a total area of 113 ha, representing 70% of the area of the former ponds. No conflicts were observed for 70 ponds with a total area of 48.3 ha (Figure 8B). However, conflicts with modern roads were noted for 83 ponds with a total area of 132.3 ha. There were no conflicts with roads for 59 water bodies with a total area of 28 ha (Figure 8C).

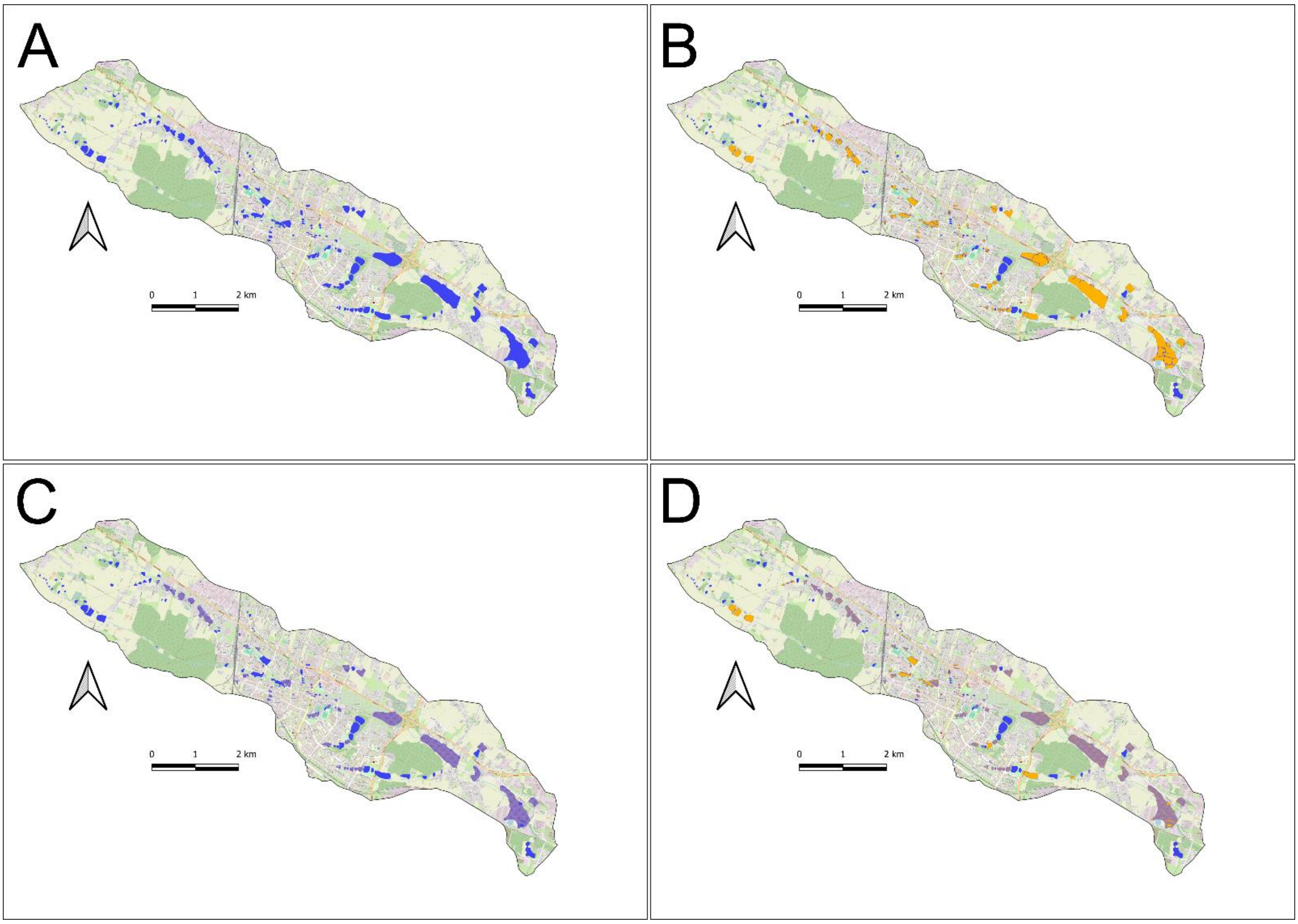

Figure 8. Analysis of the possibilities of rebuilding bead reservoirs in Potok Tyski catchment basin: (**A**) reservoirs of Potok Tyski catchment basin according to the Urmeßtischblatt (1827); (**B**) collisions of reservoirs with buildings (orange objects); (**C**) collisions of tanks with roads (violet objects); total collisions (**D**).

3.4. Preliminary Conclusions from Expert Interviews

From the experts' perspective, the issue of river renaturation and the restoration of former ponds in the GZM area is largely dependent on the level of necessary intervention in the existing urban and infrastructure fabric. In this regard, in some areas, such concepts seem more feasible to implement (such as Rzeka Mleczna (the Mleczna River), Potok Wilkowyjski (the Wilkowyjski Stream), Potok Tyski, and parts of Rzeka Gostynia), while in others, they are considered less realistic (e.g., Rzeka Rawa (the Rawa River) in the heavily urbanized areas of Katowice).

River renaturation and the restoration of former ponds are seen as very effective methods of increasing rainwater retention, both to mitigate the effects of drought and to provide flood protection. However, the main problem is the ongoing process of urban development on land that once served as natural rainwater retention areas, such as peat bogs, wetlands, meadows, and fallow land near rivers or former ponds. The problem is exacerbated by the over-regulation of rivers and streams, which drastically reduces the "width of natural channels" and sometimes the diameter of culverts.

Experts point out that, in most cases, both at the level of cities in Silesian voivodeship and across the country, there is a lack of proper management of urban catchments, which are small catchments with an area of up to several dozen square kilometers. This is something that in Anglo-Saxon terminology is referred to as a *local catchment* (in the

British literature) or *watershed* (in the American literature). According to the expert, a fundamental mistake made by decision-makers in institutions dealing with river regulations is that, within the scale of a watershed or local catchment, these areas should not be considered in isolation from the catchment area. If, as in the case of Silesian cities, the rivers often have catchments around 20 km^2, then everything happening in the valley, especially with the riverbed, is determined by what is happening in the surrounding catchment area.

In the experts' opinion, any actions regarding the management of river valleys should be preceded by an in-depth diagnosis of the current state, the causes of past changes, and the justification for the planned directions of transformation. It is essential to determine the current level of impermeability in the catchment, as well as the target level according to planning documents, and to assess what retention solutions and technical measures have already been implemented and what could be introduced.

Since the cities of the GZM area have a high degree of impermeability, any heavy rainfall, especially torrential rain, leads to immediate flooding. Therefore, according to the experts, an effective renaturation of the river valley, and even more so of the riverbed, cannot be achieved if additional "impermeable surfaces" are continuously added, which, in turn, increases the runoff of rainwater from urban areas.

On the other hand, the development and impermeabilization of the local catchment area leads to a lower and weaker groundwater level, reducing the supply to the stream. According to the experts, "whenever it is possible and socially acceptable, it should be planned in such a way that, firstly, an effort is made to maintain at least the minimum flow and, secondly, to be prepared for the fact that if these streams are seasonal or near-seasonal, they will still be important to us as blue-green corridors. That's another point".

It is also emphasized that there is no justification for separating spatial planning and environmental or hydrological issues relating to river valleys and their catchments from water and wastewater management. Rainwater management within the catchment should be treated as synonymous with river, reservoir, or stream management.

On this basis, respondents recommend the development of bioengineering measures wherever possible, such as bioengineering shoreline reinforcement and riverbed modifications to increase retention capacity. It seems necessary to introduce solutions such as SUDS (Sustainable Urban Drainage Systems). Systemic solutions related to retention and/or infiltration should be implemented, together with the management of excess rainwater at the point where it falls.

For rational water and river valley management, the authorities of each city in the GZM must have complete and detailed knowledge of how their territories are divided into local catchments, especially considering that the main watershed of Poland runs through the middle of this region.

The selected rivers of the GZM studied are perceived in various ways. Some rivers are primarily associated with a negative perception due to their level of pollution, excessive regulation, and the resulting deviation from their natural course, essentially "closed" into canals—such as Rzeka Rawa (especially in certain sections). However, there are also rivers that (at least in some parts) are better regarded in terms of water quality, functions they perform, or their potential for utilization.

In the opinion of most experts, the awareness of residents regarding the proximity of rivers/streams and reservoirs will be linked to moments of potential threats—such as flooding, inundations, etc.

4. Discussion

We entered the 21st century with the vision of a climate catastrophe and extreme weather events threatening us, which demand an intensification of adaptation efforts and a new perspective on the ecosystem services provided by aquatic environments. The intensive urbanization of the Upper Silesia region, changes in land use, and especially the increasingly noticeable and intensifying impacts of climate change, have led to changes in the categories and values of ecosystem services. The new categories of services, such as the value of ecosystem services provided by both historical and contemporary reservoirs, are different, making the existence of reservoirs in contemporary spaces economically and ecologically justified.

Available archival materials provide cross-sectional information about the land use methods in the analyzed areas. Such information can be used to verify and create spatial development plans, designate flood-prone areas, and design the restoration of blue-green infrastructure systems based on historical nature-based solutions.

4.1. The Development of the Fishing Economy in Upper Silesia

Historically, economically justified ecosystem services included fisheries and the use of impounded water to power mill wheels. These were among the major uses of reservoirs. There may have been other uses, such as water supply for agricultural purposes and ecotourism [64]. However, it is important to highlight the numerous benefits derived from increased retention, reduced erosion, and sediment accumulation in riverbeds, increased biodiversity, carbon sequestration (wetlands are one of the major carbon sinks), biogenic removal, and improved water quality.

Analyses of historical cartographic materials of the Potok Tyski catchment area have revealed significant changes in the lake area, with a high proportion of chain reservoirs/bead ponds in the catchment. Over the past 400 years, the Potok Tyski catchment has undergone substantial transformations, evolving from an agricultural area to a highly urbanized one. The cartographic documentation allows for the identification of changes in land use in the analyzed areas and the reasons for the disappearance of these water bodies.

4.2. Functions of the Bead-like Ponds

The number of bead-like ponds that existed before the intensive changes to river networks and catchments introduced by humans has significantly decreased. Bead-like ponds, which are important for biodiversity conservation [65], have been lost on a large scale during the 20th century, with losses ranging from 40 to 90% in different countries of Northwestern Europe [66]. In Switzerland, the proportion of wetlands (including ponds) lost since 1800 has been estimated at 90% [67].

River management could restore spatial heterogeneity, connectivity, retention, and resilience to some of these basins. Hence, there is a need for their restoration within relatively short time scales [68] and the reinstatement of the ecosystem services they provide. Ponds, including bead-like ponds, have been recognized as providing important network connections in landscapes, acting as “stepping stones” that facilitate the dispersal of species to neighboring areas. In these ponds, microinvertebrates find their primary habitats [69]. A large number of small ponds provide habitats for over 97% of algal populations [70]. Among various taxonomic groups, amphibians and dragonflies are strongly associated with small water bodies. Both groups are highly threatened, and in most European countries for which data are available, 20–40% of their species are generally classified as at least vulnerable. Other studies have shown lower diversity of macroinvertebrates and floral taxa in urban ponds, where management practices designed for purposes other than biodiversity (e.g., removal of aquatic vegetation [71]) and their use for energy purposes have been implemented. Ref. [72] indicates that the highest numbers of organisms from various groups are recorded in small water bodies (6–434 m^2).

Changes in the value of ecosystem services are an important factor driving changes in the land use of water-covered areas in Upper Silesia. Despite small differences in the types of ecosystem functions provided by water reservoirs, their value has undergone significant changes. The high value of fish in the Middle Ages stimulated the creation of ponds. The water energy harnessed through the use of mill wheels to power hammers in forges, millstones in mills, or saws in sawmills economically justified their maintenance. The shift away from pond management began in the 19th century when it became apparent that the market value of crops grown on the bottoms of drained reservoirs exceeded the profit from fish sales [33], and the widespread use and higher efficiency of steam engines replaced water-powered mill wheels. These factors made pond management economically unjustifiable, marking the beginning of its decline in the discussed area. Over the next 200 years, water reservoirs in Silesia were primarily used as sources of water for consumption and industry, leading to an increase in water resources through the construction of large reservoirs such as Goczałkowice, Dziećkowice, and Łąka. At the same time, the water resources of rivers became polluted, as they were treated as recipients of untreated industrial and municipal sewage, which deprived urbanized ecosystems of small water reservoirs. Studies show that in the Gostynia catchment area, the lake area index dropped from 5.77% in the 18th century to 1.09% today.

Economic changes in the Upper Silesia region in the 19th century serve as an example of the economic processes occurring at that time across Europe [36,73,74]. The shift from a nature-based economy to one based on energy derived from fossil fuels completely transformed the landscape of these areas, where the decline of water energy led to a significant reduction in the surface area of water bodies.

In the catchment area of Rzeka Gostynia, there were many artificial water reservoirs, such as embankment ponds, river ponds, and bead-like ponds. This resulted in a high lake area index for the catchment, exceeding 5%, and the methods of managing these structures indicated their considerable economic importance, as confirmed by historical sources [29,37].

In the 19th century, the number of river pond basins that existed before the morphological changes to river networks and catchments made by humans significantly declined. Today, modern water resource management of rivers and streams could lead to the restoration of these basins, recreating the former blue-green infrastructure, restoring biodiversity in the catchment area, increasing water retention, influencing the microclimate, and mitigating the effects of climate change. One must ask whether restoration should focus on the reconstruction of pond basins dispersed throughout the river network, clusters of reservoirs in relatively small stream catchments, or river reservoirs located along larger river catchments [4,5].

The functions of the bead-like ponds are still very important today. Therefore, the restoration of the bead-like ponds is becoming a challenge in river renaturation processes. The benefits of such solutions include the response of rivers and streams to extreme climate events, increased water retention, trapping of diverse materials, reduced erosion, and increased ecosystem stability [5]. An important environmental aspect is the increased biological diversity of such ecosystems. Wohl and colleagues [5] point out that the original river network was characterized by numerous bead-like ponds. The benefits of having bead-like ponds in the catchment result from increased retention, reduced erosion, and sediment accumulation in the riverbed. These functions of bead-like ponds are still highly relevant today. Therefore, the restoration of bead-like ponds is emerging as a key challenge in river renaturation processes.

It is important to consider the aspect of ecological losses in renaturation (which in turn translates into economic changes), while, on the other hand, analyzing the ecosystem gains resulting from their restoration by assessing the ecosystem value of restored retention and increased biodiversity. The second implication relates to river management aimed at increasing retention and resilience in river networks.

Dams effectively reduce the number and function of river pools. These changes have likely caused rivers to behave more like pipes, passively transporting materials further along the process, rather than acting as reactors where materials are processed and stored [75].

5. Conclusions

Experts show that, in recent decades, the water balance structure of catchment areas has significantly deteriorated due to weather conditions, increased surface sealing, and the density and type of vegetation cover, which influence the volume and speed of rainfall, which influence the rate of surface runoff.

From the Middle Ages to the beginning of the 19th century, bead-like ponds [1] played an important role in the human economy as a water source for energy processing by the mill wheels in factories or as a source of food (drinking water, fish) [2]. An indirect effect of the existence of bead-like ponds was the impact on the microclimate.

The process of eliminating bead-like ponds began in the 1850s due to a decline in the value they performed of ecosystem services. However, given the consequences of climate change, these reservoirs are now regaining their importance, and their maintenance has once again become economically justified.

This causes a change in the value of ecosystem services, such as carbon sequestration, microclimate regulation, water retention, and cultural values related to mitigating the effects of climate change. It indicates a high potential for the restoration of bead-like ponds in the study area.

Key to the location of the historic blue-green infrastructure are old 17th- and 19th-century maps that allow the identification of numerous bead-like reservoirs in the Potok Tyski catchment.

Analyzing several areas of spatial conflict where surfaces of bead-like ponds are being converted into areas for residential development, old maps and Digital Terrain Models (DEM) indicate the presence of remnants of hydraulic structures. It may lead to flashwater swells and urban floods during heavy rains.

It shows that old maps can be helpful in the preparation of spatial development plans by identifying areas that should not be developed because of increased flood risk.

Despite spatial conflicts, the reconstruction of pond basins should be considered, as they can serve as the foundation for creating blue-green infrastructure. They will act as a link between blue-green infrastructure and elements of gray infrastructure, enhancing ecological biodiversity and mitigating the effects of climate change.

The restoration of bead-like ponds will increase water retention in the environment and will impact mitigating the effects of climate change. This solution can be considered one of the examples of nature-based solutions (NBS), where the goal is achieved using natural methods.

This indicates the important role of bead-like pond restoration in shaping blue-green infrastructure.

Both urban and agricultural landscapes will benefit from restored ponds. Most importantly, they will help to improve the structure of water resources and enhance biodiversity while also having potential for economic use.

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